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Eickelmann et al.

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(54) **ENERGY HARVESTING DEVICE WITH PREFABRICATED THIN FILM ENERGY ABSORPTION SHEETS AND ROLL-TO-SHEET AND ROLL-TO-ROLL FABRICATION THEREOF**

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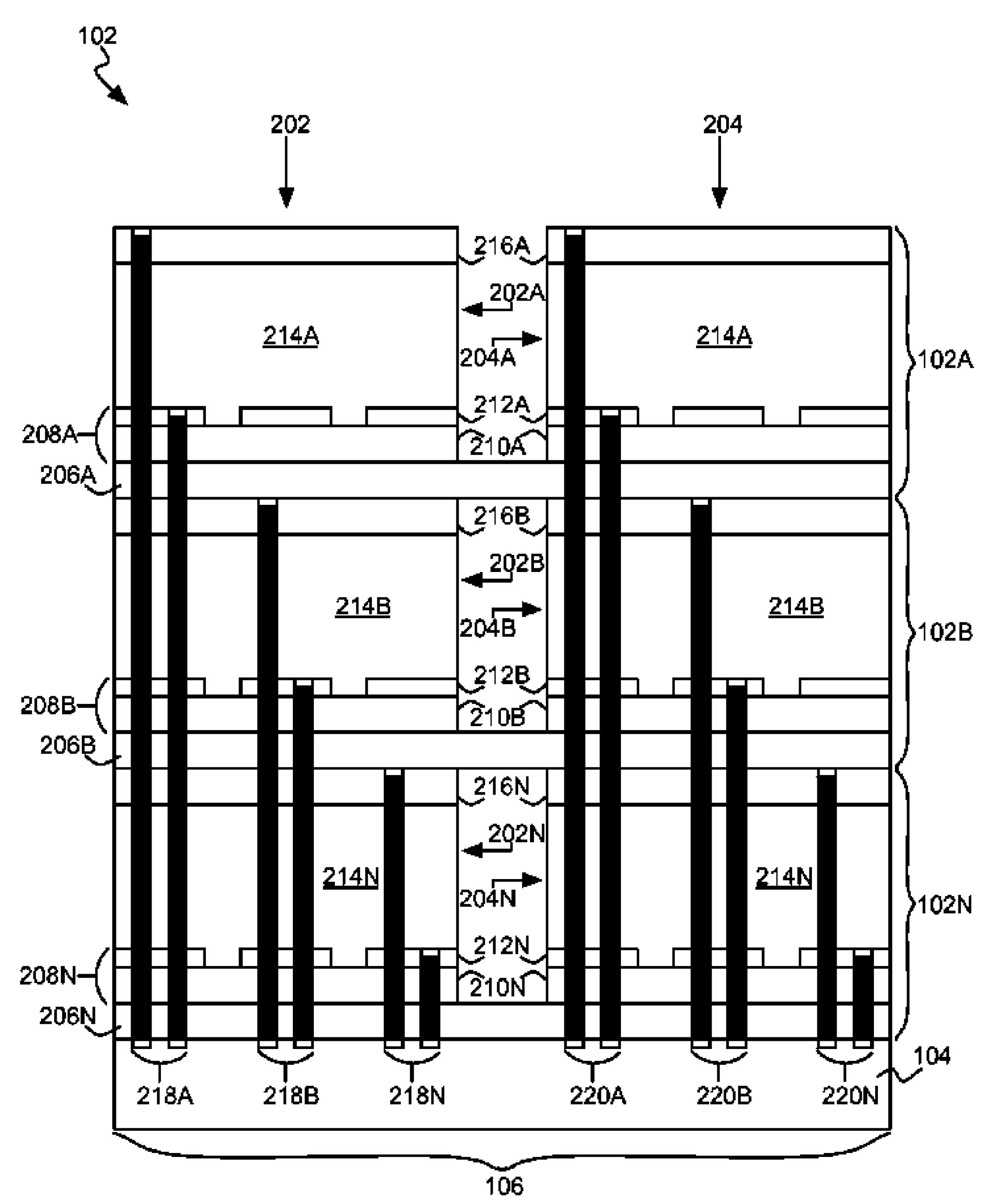
(57) **ABSTRACT**

An energy harvesting device includes prefabricated thin film energy absorption sheets that are each tuned to absorb electromagnetic energy of a corresponding wavelength. The energy harvesting device can include a prefabricated thin film converter sheet to convert the electromagnetic energy into electrical power. The energy harvesting device can include a prefabricated thin film battery sheet to store the electrical power. Each thin film energy absorption sheet can be fabricated using a roll-to-roll process. The energy harvesting device can be fabricated using a roll-to-sheet process from rolls of the thin film energy absorption sheets.

2 Claims, 6 Drawing Sheets



(51) **Int. Cl.**
H01L 31/0725 (2012.01)
H01L 31/18 (2006.01)

(52) **U.S. Cl.**
CPC .. ***H01L 31/022466*** (2013.01); ***H01L 31/0725*** (2013.01); ***H01L 31/1884*** (2013.01); *Y02E 10/50* (2013.01)

(58) **Field of Classification Search**
USPC 136/243–265
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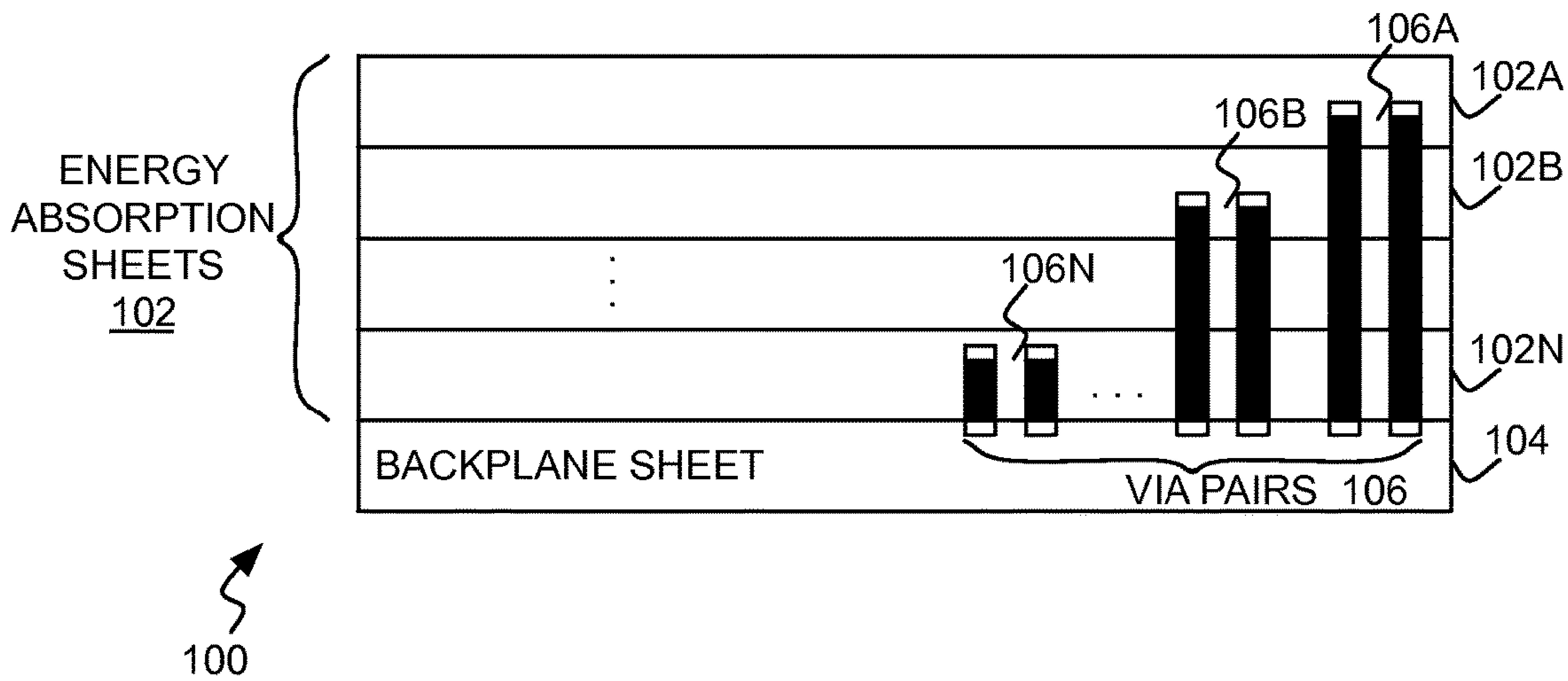
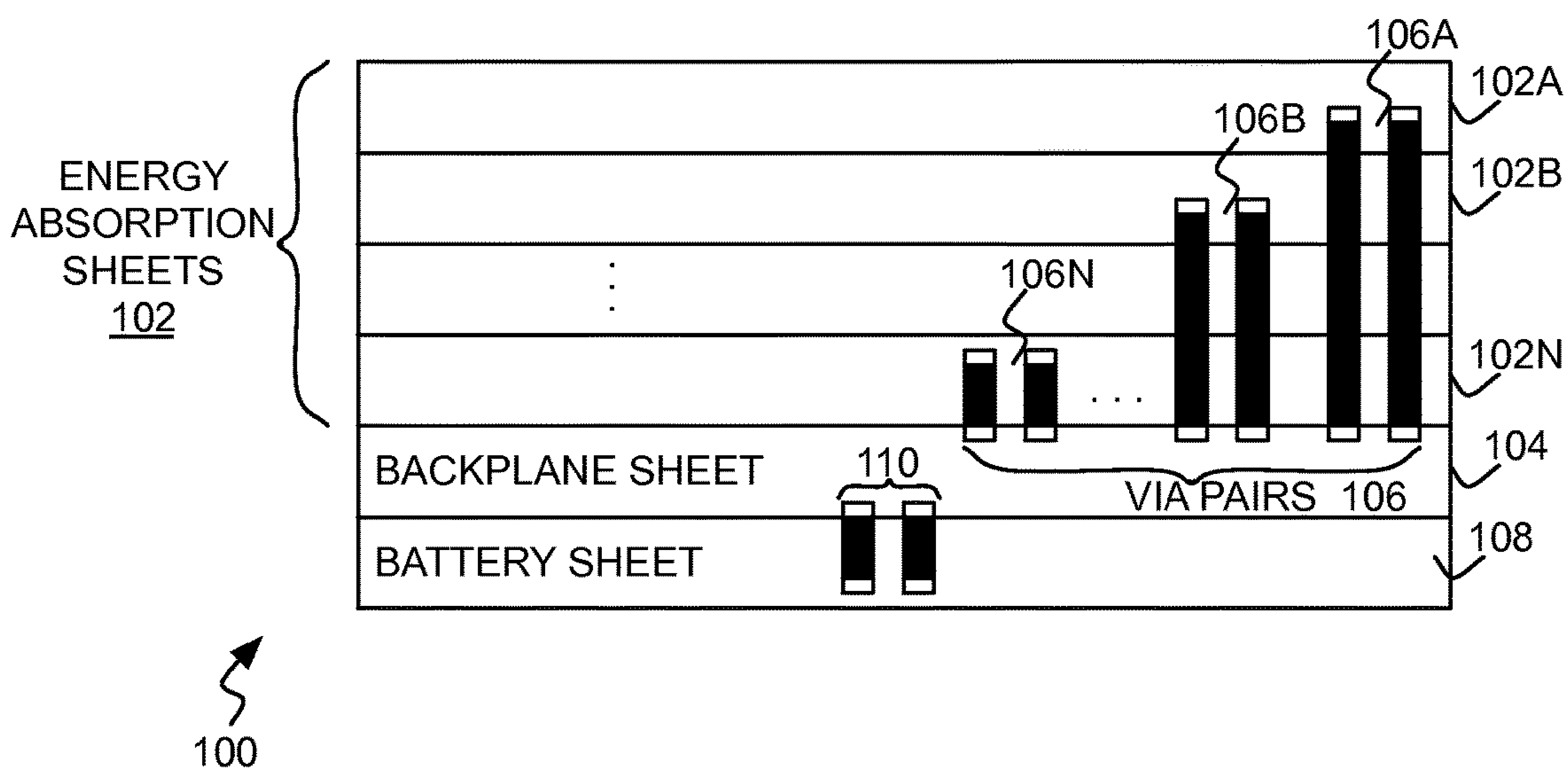
FIG 1A



ENERGY ABSORPTION SHEETS 102
106A
102A
106B
102B
106N
102N
BACKPLANE SHEET
VIA PAIRS 106
104
100

FIG 1B



ENERGY ABSORPTION SHEETS 102
106A
102A
106B
102B
106N
102N
BACKPLANE SHEET
110
VIA PAIRS 106
104
BATTERY SHEET
108
100

FIG 2A

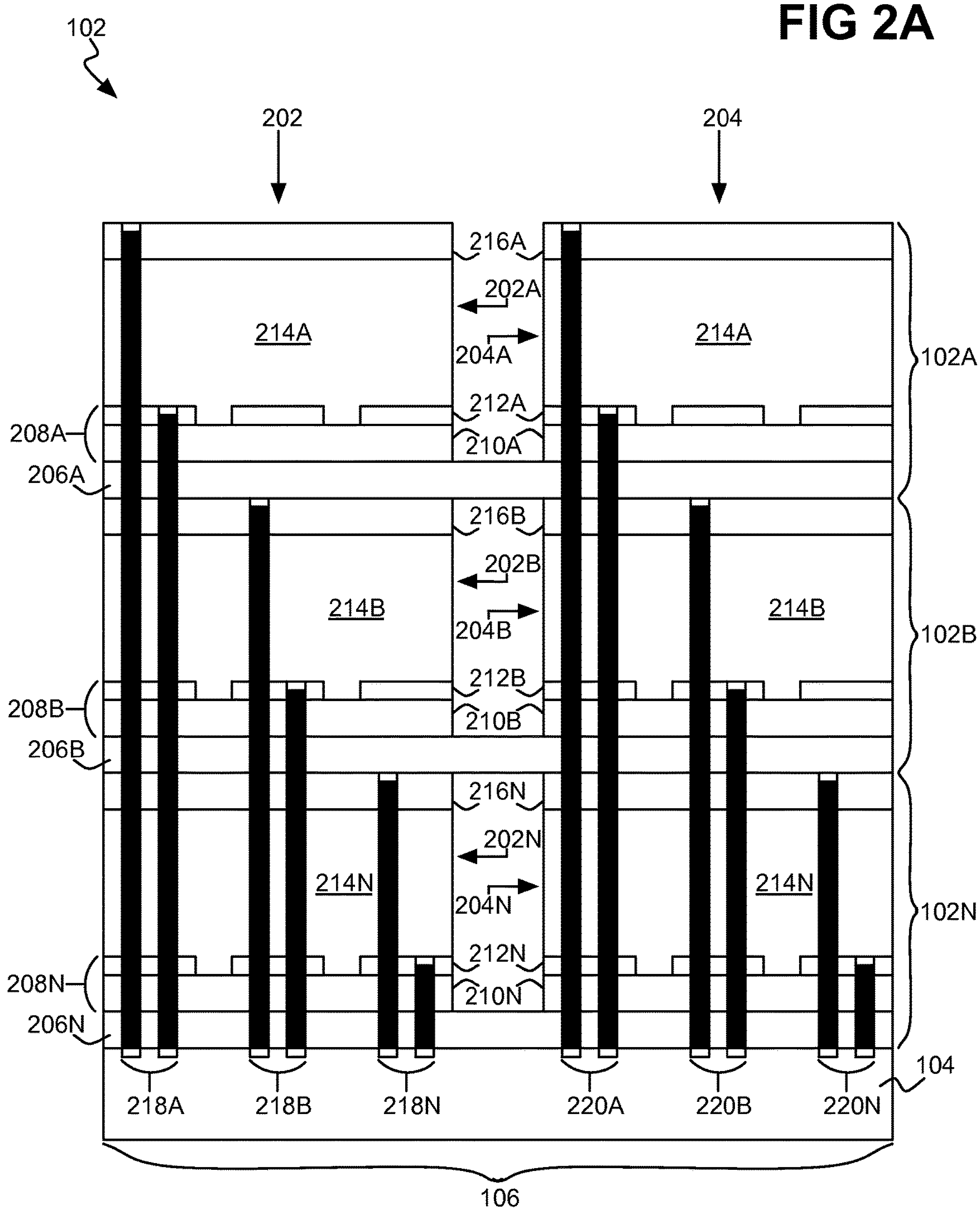
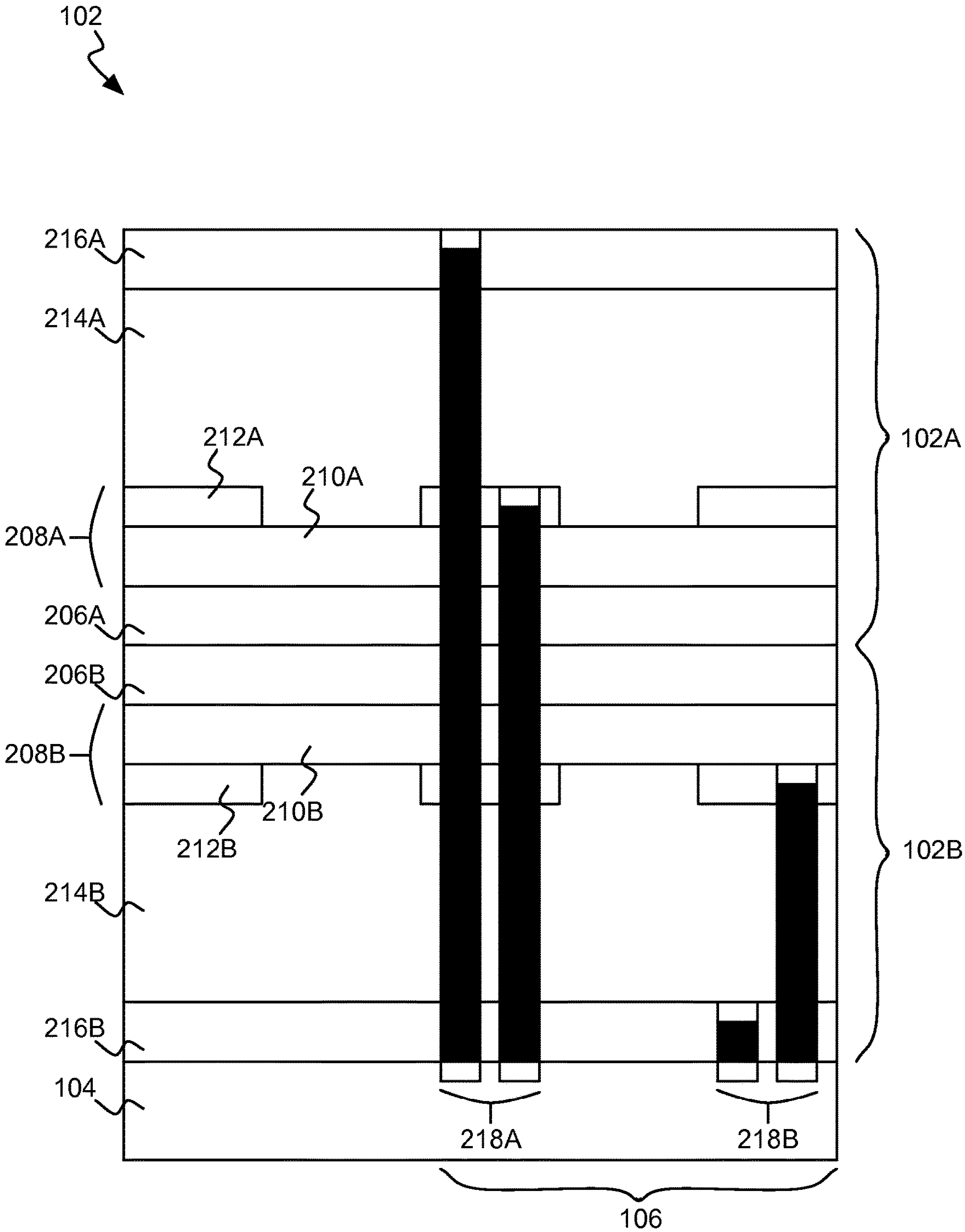

102
202
204
216A
202A
214A
204A
214A
102A
212A
208A
210A
206A
216B
202B
214B
204B
214B
102B
212B
208B
210B
206B
216N
202N
214N
204N
214N
102N
212N
208N
210N
206N
104
218A
218B
218N
220A
220B
220N
106

FIG 2B



102
216A
214A
212A
210A
208A
206A
206B
208B
210B
212B
214B
216B
104
218A
218B
106
102A
102B

FIG 3A

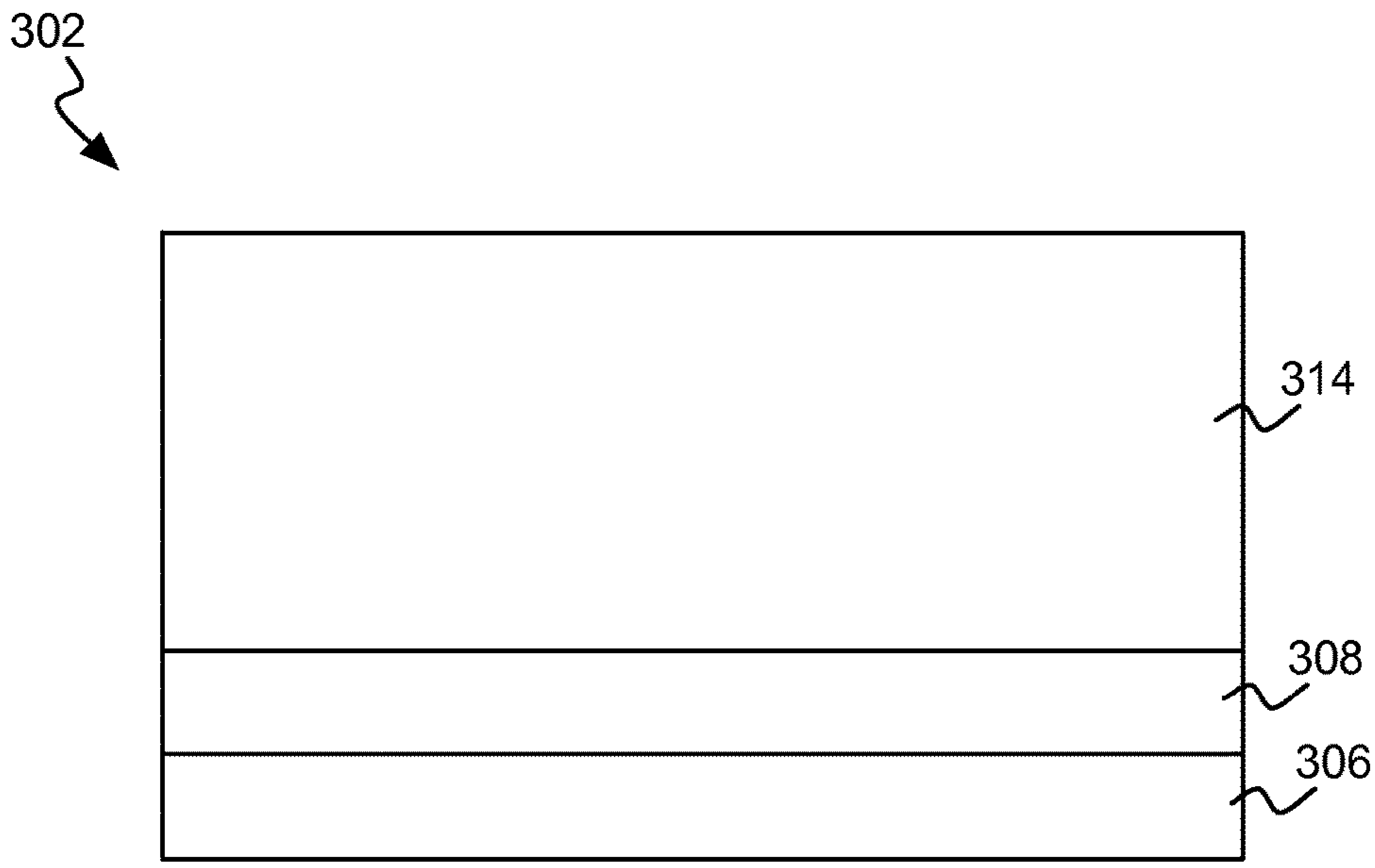


FIG 3B

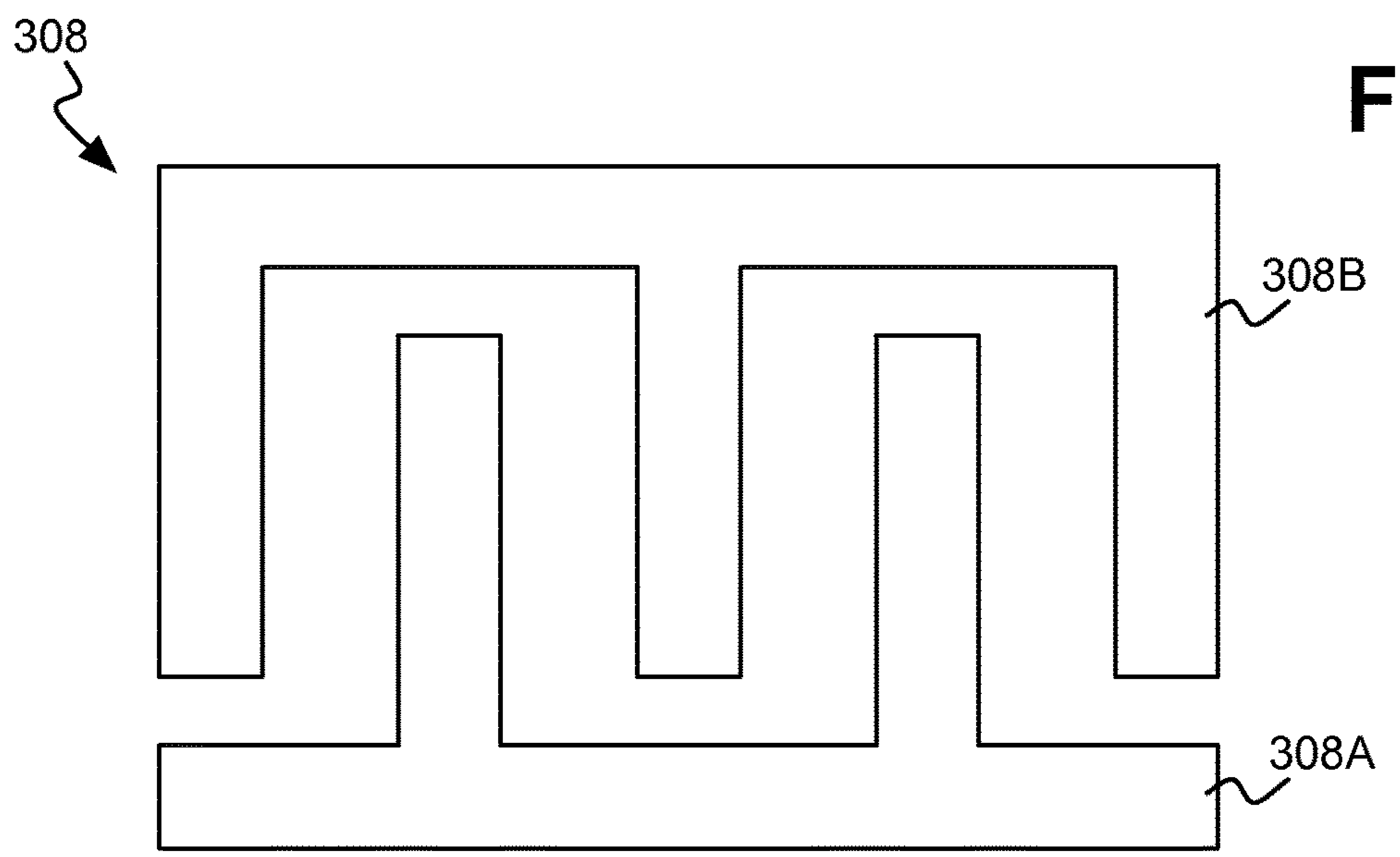


FIG 4

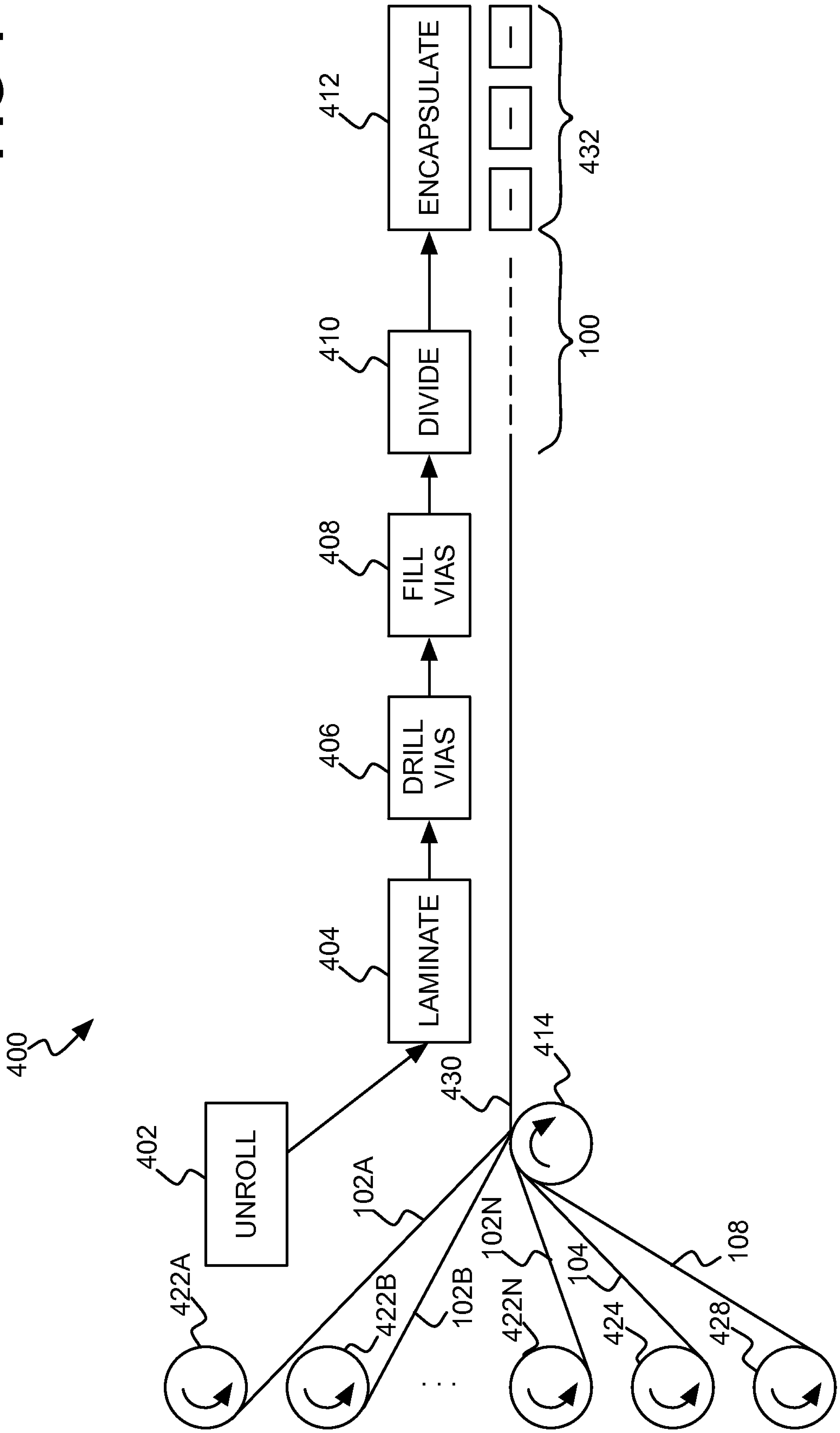
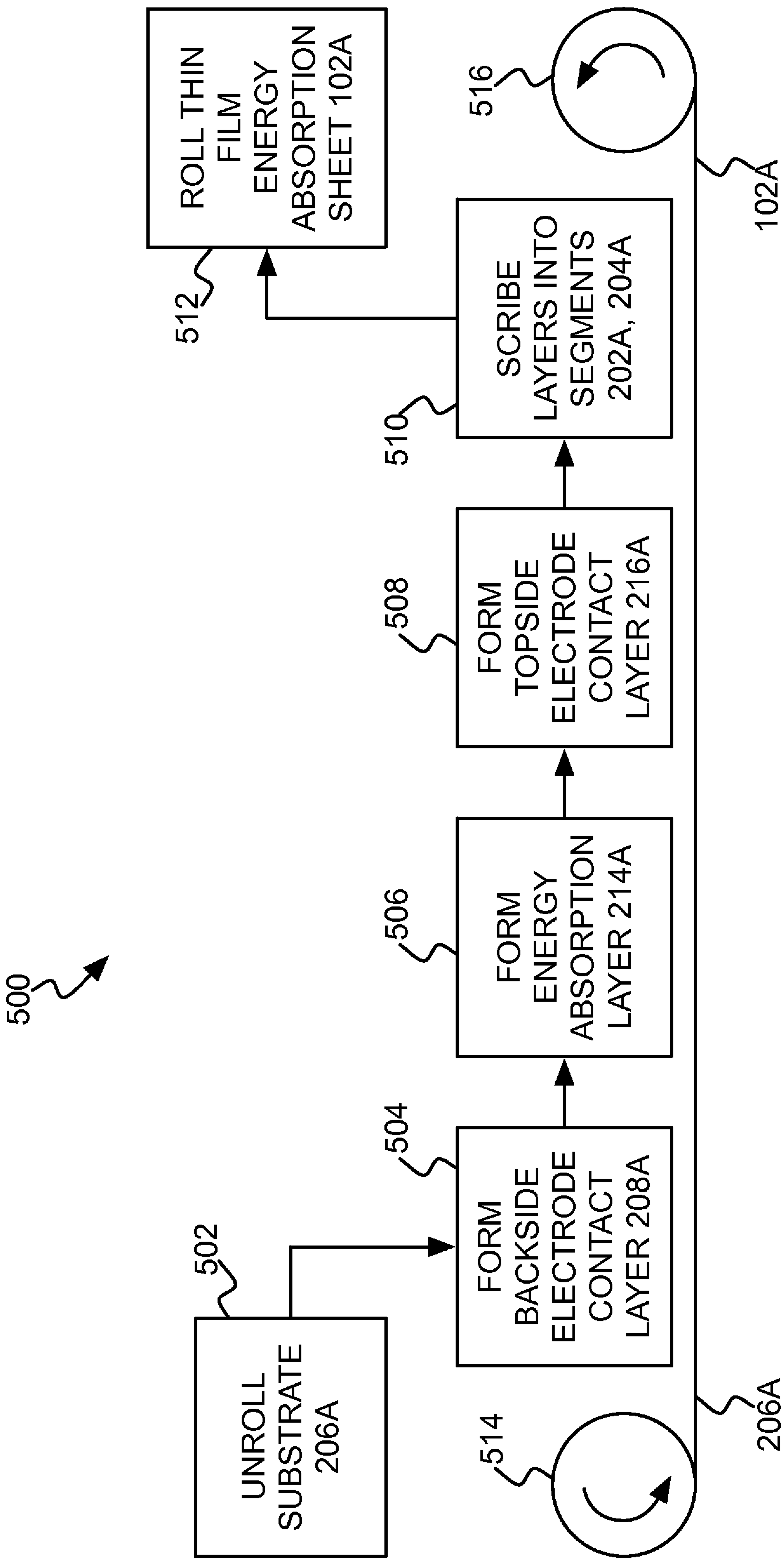

400
402
UNROLL
404
LAMINATE
406
DRILL VIAS
408
FILL VIAS
410
DIVIDE
412
ENCAPSULATE
432
100
430
414
102A
102B
102N
104
108
422A
422B
422N
424
428
. . .

FIG 5


500
502
UNROLL SUBSTRATE 206A
504
FORM BACKSIDE ELECTRODE CONTACT LAYER 208A
506
FORM ENERGY ABSORPTION LAYER 214A
508
FORM TOPSIDE ELECTRODE CONTACT LAYER 216A
510
SCRIBE LAYERS INTO SEGMENTS 202A, 204A
512
ROLL THIN FILM ENERGY ABSORPTION SHEET 102A
514
516
206A
102A

ENERGY HARVESTING DEVICE WITH PREFABRICATED THIN FILM ENERGY ABSORPTION SHEETS AND ROLL-TO-SHEET AND ROLL-TO-ROLL FABRICATION THEREOF

BACKGROUND

Electronic devices widely vary in size, shape, and functionality, but all share a common need for electrical power. Typical powering schemes include plugging in the devices to alternating current (AC) mains via a wall outlet, as well as using batteries that may be recharged by similarly being plugged into AC mains. More recently, solar cells have become an approach by which electronic devices can be powered by converting solar energy into electrical energy.

SUMMARY

An example energy harvesting device includes a backplane sheet. The device includes prefabricated thin film energy absorption sheets attached to the backplane sheet and organized in a stack from a top sheet to a bottom sheet. Each energy absorption sheet is attached to at least one other energy absorption sheet. Each energy absorption sheet includes an energy absorption layer tuned to absorb electromagnetic energy of a corresponding wavelength, and one or more electrode contact layers in contact with the energy absorption layer. The energy harvesting device includes pairs of vias corresponding to the energy absorption sheets. Each pair of vias is filled with a conductive material, and extends from the backplane sheet through the stack to the electrode contact layers of a corresponding energy absorption sheet.

An example roll-to-sheet method for fabricating energy harvesting devices includes unrolling prefabricated thin film sheets, including prefabricated thin film energy absorption sheets, from corresponding rolls of the prefabricated thin film sheets into which the prefabricated thin film sheets have been wound. The method includes laminating the thin film sheets together after unrolling, and drilling vias through the thin film sheets after lamination. The method includes filling the vias with a conductive material, and dividing the thin film sheets into the energy harvesting devices after drilling and filling the vias. The thin film energy absorption sheets absorb electromagnetic energy.

An example roll-to-roll method for fabricating a thin film energy absorption sheet includes unrolling a thin film substrate from a roll, and forming an energy absorption layer on the thin film substrate after unrolling, the energy absorption layer tuned to absorb electromagnetic energy of a corresponding wavelength. The method includes forming one or more electrode contact layers on the thin film substrate after unrolling. The energy absorption layer and the electrode contact layers are in contact with one another. The method includes rolling the thin film substrate with the energy absorption layer and the electrode contact layers formed thereon into a roll of the thin film energy absorption sheet.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings referenced herein form a part of the specification. Features shown in the drawing illustrate only some embodiments of the disclosure, and not of all embodiments of the disclosure, unless the detailed description explicitly indicates otherwise, and readers of the specification should not make implications to the contrary.

FIGS. **1**A and **1**B are diagrams of example energy harvesting devices.

FIGS. **2**A and **2**B are diagrams of example prefabricated thin film energy absorption sheet stacks.

FIG. **3**A is a diagram of an example prefabricated thin film energy absorption sheet having an interdigitated electrode contact layer, and FIG. **3**B is a diagram of a plan view of an example interdigitated electrode contact layer.

FIG. **4** is an illustrative flowchart of an example roll-to-sheet method for fabricating multiple energy harvesting devices.

FIG. **5** is an illustrative flowchart of an example roll-to-roll method for fabricated a thin film energy absorption sheet.

DETAILED DESCRIPTION

The following detailed description of exemplary embodiments of the disclosure refers to the accompanying drawings that form a part of the description. The drawings illustrate specific exemplary embodiments in which the disclosure may be practiced. The detailed description, including the drawings, describes these embodiments in sufficient detail to enable those skilled in the art to practice the disclosure. Those skilled in the art may further utilize other embodiments of the disclosure, and make logical, mechanical, and other changes without departing from the spirit or scope of the disclosure.

As noted in the background section, solar cells are one way to power electronic devices. Historically, solar cells have suffered from two primary deficiencies. First, their efficiency at converting electromagnetic energy to electrical energy that can be used to power devices has been relatively low. Second, the fabrication of such solar cells has been relatively difficult and expensive. Both of these deficiencies have limited the extent to which solar cells have been integrated into electronic devices.

Disclosed herein is an energy harvesting device. The device is an energy harvesting device in that it harvests energy, such as electromagnetic energy from the sun or other visible light sources, so that the energy can be used for other applications, such as the powering of electronic devices. The energy harvesting device includes a backplane sheet to which prefabricated thin film sheets, including prefabricated thin film energy absorption sheets, are attached.

The thin film energy absorption sheets are organized in a stack, and each sheet is tuned to absorb electromagnetic energy of a corresponding wavelength, such as the same or different wavelengths of visible light. A roll-to-roll fabrication technique can be used to fabricate each individual thin film energy absorption sheet, and a roll-to-sheet fabrication technique can be used to fabricate energy harvesting devices from such prefabricated sheets. Other prefabricated thin film energy absorption sheets that can be integrated within the energy harvesting devices include the backplane sheet, thin film power converter sheets, thin film battery sheets, and/or combined thin film power converter-battery sheets. As described below, these techniques overcome the deficiencies with existing solar cells.

FIGS. **1**A and **1**B show an example energy harvesting device **100**. The energy harvesting device **100** includes prefabricated thin film energy absorption sheets **102**. The energy absorption sheets **102** include individual such sheets **102**A, **102**B, . . . , **102**N. There are at least two energy absorption sheets **102**. The energy absorption sheets **102** are organized in a stack from the top sheet **102**A to the bottom sheet **102**N. As depicted in FIGS. **1**A and **1**B, each energy absorption sheet **102** is attached to at least one other energy absorption sheet **102**. Each energy absorption sheet **102** absorbs electromagnetic energy of a corresponding wavelength.

The energy harvesting device **100** can include a prefabricated thin film backplane sheet **104** attached to the bottom energy absorption sheet **102**N. In the examples of both FIGS. **1**A and **1**B, the backplane sheet **104** can be a power converter sheet. The power converter sheet converts the electromagnetic energy absorbed by the energy absorption sheets **102** into electrical power. In the example of FIG. **1**A, the backplane sheet **104** can be a combined power converter-battery sheet, which both converts the electromagnetic energy absorbed by the energy absorption sheets **102** into electrical power and stores the electrical power.

In the example of FIG. **1**B, by comparison, there is a separate prefabricated thin film battery sheet **108** attached to the backplane sheet **104**, and which stores the electrical power generated by the backplane sheet **104**. An example of a backplane sheet **104** that is a power converter sheet is described in US published patent application number 2015/0047686. An example of a battery sheet **108** is described in the U.S. patent application having the application Ser. No. 14/589,233.

The energy harvesting device **100** includes conductive material-filled via pairs **106** corresponding to the energy absorption sheets **102**. The via pairs **106** include via pairs **106**A, **106**B, . . . , **106**N that correspond to the energy absorption sheets **102**A, **102**B, . . . , **102**N, respectively. Each via pair **106** includes two vias that are conductively connected to the backplane sheet, extend from the backplane sheet **104**, and conductively connect to a corresponding energy absorption sheet **102**. Each via pair **106** is not conductively connected to any intermediate energy absorption sheet **102** between the backplane sheet **104** and its corresponding energy absorption sheet **102**. Each via is filled with a conductive material, such as a metallic material like copper, aluminum, or an alloy, among others, or a non-metallic conductive material that is at least substantially transparent. The via pairs **106** permit the energy absorbed by the energy absorption sheets **102** to be routed to the backplane sheet **104**.

In the example of FIG. **1**B, there is also a conductive material-filled via pair **110** for the battery sheet **108**. The via pair **110** includes two vias that are conductively connected to the backplane sheet, extend from the backplane sheet **104**, and conductively connect to the battery sheet **108**. Each via is filled with a conductive material. The via pair **110** permits the electrical energy generated by the backplane sheet **104** to be routed to the battery sheet **108**.

FIG. **2**A shows an example of the prefabricated thin film energy absorption sheets **102** of the energy harvesting device **100**. The backplane sheet **104** is also depicted in FIG. **2**A, and in another implementation, the device **100** can include the battery sheet **108** as well. There are three energy absorption sheets **102**A, **102**B, and **102**N, which can absorb electromagnetic energy of the same or different corresponding wavelengths. For example, the energy absorption sheets **102**A, **102**B, and **102**N can absorb electromagnetic energy of blue, green, and red visible light wavelengths, respectively.

The energy absorption sheets **102** are segmented into two energy absorption cells **202** and **204**. In other implementations, there can be more than two energy absorption cells. The sheet **102**A is segmented into cells **202**A and **204**A; the sheet **102**B is segmented into cells **202**B and **204**B; and the sheet **102**N is segmented into cells **202**N and **204**N. In one implementation, the backplane sheet **104** can include a separate power converter device for each energy absorption cell **202** and **204**. Therefore, if one cell **202** or **204** becomes damaged, it will not affect the other, undamaged cell **204** or **202**.

The energy absorption sheets **102**A, **102**B, and **102**N have corresponding backside layers **206**A, **206**B, and **206**N, respectively. The backside layers **206**A, **206**B, and **206**N are substrate layers, and may have a thickness between fifty and one-hundred micrometers. The backside layers **206**A, **206**B, and **206**N may be glass foil or another material. In the example of FIG. **2**, no backside layer is adjacent any other backside layer.

The energy absorption sheets **102**A, **102**B, and **102**N have bottom, or backside, electrode contact layers **208**A, **208**B, and **208**N, respectively. The electrode contact layers **208**A, **208**B, and **208**N may be a substantially transparent structured metal nanowire layer. For example, the electrode contact layer **208**A can include a transparent insulating layer **210**A on or within which a conductive wire network layer **212**A is formed. Likewise, the electrode contact layer **208**B can include a transparent insulating layer **210**B and a conductive wire network layer **212**B, and the electrode contact layer **208**N can include a transparent insulating layer **210**N and a conductive wire network layer **212**N.

The transparent insulating layers **210**A, **210**B, and **210**N may be aluminum oxide, an ultraviolet (UV)-cured polymer material, or another type of material. The conductive wire network layers **212**A, **212**B, and **212**N may be molybdenum, silver, copper, aluminum, or another type of material. In another implementation, the bottom electrode contact layers **208**A, **208**B, and **208**N are a transparent conductive material like a transparent conductive oxide (TCO) such as indium tin oxide (ITO) or zinc oxide with aluminum, instead of transparent insulating layers **210**A, **210**B, and **210**N on or within which conductive wire network layers **212**A, **212**B, and **212**N are formed.

The energy absorption sheets **102**A, **102**B, and **102**N have energy absorption layers **214**A, **214**B, and **214**N, respectively. The energy absorption layers **214**A, **214**B, and **214**N are tuned to absorb electromagnetic energy of corresponding wavelengths. The energy absorption layers **214**A, **214**B, and **214**N are semiconductive materials, such as gallium arsenide, indium phosphide, indium gallium phosphide, indium gallium arsenide, germanium, or another type of semiconductive material. For instance, other types of semiconductive materials include copper indium gallium selenide (CIGS), copper zinc tin sulfide (CZTS), and cadmium magnesium telluride, among others. Still other types of semiconductive materials that can be employed include organic-inorganic perovskite, and other organic photovoltaic materials that can be tuned to a desired absorption wavelength. The semiconductive materials may be grown using epitaxial growth, vacuum deposition, electroplating, inkjet printing, and transfer-bonding crystalline thin film processes, among others.

The energy absorption sheets **102**A, **102**B, and **102**N have top, or topside, electrode contact layers **216**A, **216**B, and **216**N, respectively. The electrode contact layers **216**A, **216**B, and **216**N may be a transparent conductive material like a TCO such as ITO or zinc oxide with aluminum. In another implementation, the top electrode contact layers **216**A, **216**B, and **216**N may be transparent insulating layers on or within which conductive wire network layers are formed. In the example of FIG. **2**A, the energy absorption sheets **214**A, **214**B, and **214**N are in contact with and disposed between the bottom electrode contact layers **208**A, **208**B, and **208**N and the top electrode contact layers **216**A, **216**B, and **216**N.

The via pairs **106** that have been described include two via pairs for each energy absorption sheet **102**A, **102**B, and **102**N, in correspondence with the number of energy absorption cells **202** and **204**. Stated another way, there are separate via pairs **106** for each energy absorption sheet **102**A, **102**B, and **102**N of each energy absorption cell **202** and **204**. Specifically, there are via pairs **218**A, **218**B, and **218**N for the energy absorption cells **202**A, **202**B, and **202**N, respectively. Similarly, there are via pairs **220**A, **220**B, and **220**N for the energy absorption cells **204**A, **204**B, and **204**N, respectively.

Each via pair includes one via that extends from the backplane sheet **104** and conductively connects to the bottom electrode contact layer of a corresponding energy absorption sheet, and another via that extends from the bottom of the energy absorption sheets to the top electrode contact layer of this corresponding energy absorption sheet. The via pair **218**A is described as representative of the other via pairs **218**B, **218**N, **220**A, **220**B, and **220**N in this respect. The right via of the via pair **218**A extends from the backplane sheet **104** and conductively connects to the bottom electrode contact layer **212**A of the energy absorption sheet **102**A. The left via of the via pair **218**A extends from the backplane sheet **104** and conductively connects to the top electrode contact layer **216**A of the energy absorption sheet **102**A.

FIG. **2**B shows another example of the prefabricated thin film energy absorption sheets **102** of the energy harvesting device **100**. The backplane sheet **104** is also depicted in FIG. **2**B, and in another implementation, the device can include the battery sheet **108** as well. There are two energy absorption sheets **102**A and **102**B that can absorb electromagnetic energy of the same or different corresponding wavelengths. For example, the energy absorption sheets **102**A and **102**B may absorb electromagnetic of blue and red visible light wavelengths, respectively.

The energy absorption sheets **102**A and **102**B are organized in a tandem configuration, in which the backside layer **206**A of the sheet **102**A and the backside layer **206**B of the sheet **102**B are directly adjacent one another. Otherwise, the energy absorption sheets **102**A and **102**B are as have been described in relation to FIG. **2**A. The energy absorption sheets **102**A and **102**B have bottom electrode contact layers **208**A and **208**B, respectively, which may be a substantially transparent structured metal nanowire layer. The electrode contact layer **208**A thus can include the transparent insulating layer **210**A on or within which the conductive wire network layer **212**A is formed, and the electrode contact layer **208**B can include the transparent insulating layer **210**B on or within which the conductive wire network layer **212**B is formed.

The energy absorption sheets **102**A and **102**B have energy absorption layers **214**A and **214**B, respectively, which are tuned to absorb electromagnetic energy of corresponding wavelengths. The energy absorption sheets **102**A and **102**B have top electrode contact layers **216**A and **216**B, respectively, which may be a transparent conductive material. The via pairs **106** include the via pairs **218**A and **218**B corresponding to the energy absorption sheets **102**A and **102**B, respectively. The via pair **218**A is conductively connected to the backplane sheet **104**, extend from the backplane sheet **104**, and conductively connect to the energy absorption sheet **102**A. Specifically, the via pair **218**A includes one via that conductively connects to the top electrode contact layer **216**A and another via that conductively connects to the bottom electrode contact layer **208**A. The via pair **218**B is conductively connected to the backplane sheet **104**, extend from the backplane sheet **104**, and conductively connected to the energy absorption sheet **102**B. Specifically, the via pair **218**B includes one via that conductively connects to the top electrode contact layer **216**B and another via that conductively connects to the bottom electrode contact layer **208**B.

The tandem configuration of FIG. **2**B can be segmented like the non-tandem configuration of FIG. **2**A in another implementation. Similarly, the non-tandem configuration of FIG. **2**A may not be segmented like the tandem configuration of FIG. **2**A in another implementation. That is, either configuration may not be segmented into separate energy absorption cells, or may be segmented into two or more energy absorption cells.

FIG. **3**A shows an example of a single prefabricated thin film energy absorption sheet **302**. The energy absorption sheet **302** can be used in lieu of any of the energy absorption sheets **102** that have been described. In the example of FIG. **3**A, the energy absorption sheet **302** includes a backside layer **306** like the backside layers **206**A, **206**B, and **206**N that have been described, as well as an energy absorption layer **314** like the energy absorption layers **214**A, **214**B, and **214**N have been described.

However, in FIG. **3**A, rather than both a top electrode contact layer and a bottom electrode contact layer, there is one interdigitated electrode contact layer **308**. In the example of FIG. **3**A, the interdigitated electrode contact layer **308** is shown as a bottom such layer, between the backside layer **306** and the energy absorption layer **314**. In another implementation, the interdigitated electrode contact layer **308** can be a top such layer, above the energy absorption layer **314**, in which case the energy absorption layer **314** is in direct contact with the backside layer **306**.

FIG. **3**B shows a plan view of an example of the interdigitated electrode contact layer **308**. The interdigitated electrode contact layer **308** has two parts **308**A and **308**B that are electrically isolated from one another within the layer **308** itself. Having an interdigitated electrode contact layer **308** means that there can be just one electrode contact layer **308** within the prefabricated thin film energy absorption sheet **302**. When the interdigitated contact layer **308** is employed, it includes two materials: a first material that forms a rectifying junction in relation to the energy absorption layer **314**, and a second material that forms an ohmic contact in relation to the energy absorption layer **314**.

FIG. **4** illustratively shows an example roll-to-sheet method **400** for fabricating energy harvesting devices **100** from prefabricated thin film sheets. The method **400** is described in relation to instances of the energy harvesting device **100** of FIG. **1**B, but is applicable to the energy harvesting device **100** of FIG. **1**A as well. The prefabricated thin film sheets include the energy absorption sheets **102**A, **102**B, . . . , **102**N, the backplane sheet **104** and the battery sheet **108**, which have been prefabricated and wound onto corresponding continuous rolls **422**A, **422**B, . . . , **422**N, **424**, and **428**, respectively.

The rolls **422**A, **422**B, . . . , **422**N, **424**, and **428** are unrolled (**402**) using a roller **414**, to result in a thin film sheet stack **430** of the prefabricated thin film sheets **102**A, **102**B, . . . , **102**N, **104**, and **108**. The thin film sheets **102**A, **102**B, . . . , **102**N, **104**, and **108** of the thin film sheet stack **430** are laminated together (**430**). For example, the thin film sheets **102**A, **102**B, . . . , **102**N, **104**, and **108** can be laminated via bonding, or by being adhesively attached together. The via pairs **106**, **108**, and **110** of FIG. **1**B are formed through the thin film sheet stack **430** by drilling (**406**), and then filled with a conductive material (**408**), such as by electroplating.

The result of the method **400** from part **402** through part **408** is a thin film sheet stack **430** having multiple energy harvesting devices **100**. Therefore, the thin film sheet stack **430** is divided into individual energy harvesting devices **100** (**410**), such as via singulation. The individual energy harvesting devices **100** can then be encapsulated (i.e., packaged) into separate energy harvesting device modules **432** (**412**) for use within electronic devices.

FIG. **5** illustratively shows an example roll-to-roll method **500** for fabricating a thin film energy absorption sheet, which can then be used as a prefabricated such sheet in the method **400**. The method **500** is described in relation to the thin film energy absorption sheet **102**A of FIG. **2**A, but is more generally applicable in relation to other types of thin film energy absorption sheets as well. The method **500** starts by unwinding or unrolling a roll **514** of the backside layer **206**A (**502**), which is a substrate layer.

The bottom electrode contact layer **208**A can be formed on the backside layer **206**A (**504**). For example, the insulating layer **210**A may be deposited as a passivation layer on the backside layer **206**A, and the conductive wire network layer **212**A formed on or within the insulating layer **210**A. In one implementation, formation of the conductive wire network layer **212**A can be achieved by depositing a conductive material in accordance with the desired network topology. In another implementation, formation of the conductive wire network layer **212**A can be achieved by depositing a sacrificial layer of the conductive material, performing nano imprint lithography to structure the sacrificial layer in correspondence with the desired network topology, and then etching the conductive material to realize the desired network topology. As another example, the bottom electrode contact layer **208**A can be formed by depositing a transparent electrode contact layer, which may be interdigitated if the bottom electrode contact layer **208**A is the only electrode contact layer of the thin film energy absorption sheet **102**A.

The energy absorption layer **214**A is formed (**506**). For example, a semiconducting energy absorbing material may be deposited. The topside electrode contact layer **216**A can be formed on the energy absorption layer **214**A (**508**). For example, the topside electrode contact layer **216**A can be formed by depositing a transparent electrode contact layer, which may be interdigitated if the topside electrode contact layer **216**A is the only electrode contact layer of the thin film energy absorption sheet **102**A. The layers **208**A, **214**A, and **216**A can be scribed into segmented energy absorption cells **202**A and **204**A (**510**).

The result of the method **500** from part **502** through part **510** is the thin film energy absorption sheet **102**A. The thin film energy absorption sheet **102**A is wound or rolled into a roll **516** of the thin film energy absorption sheet **102**A (**512**). This roll **516** can then be used as one of the rolls **422**A, **422**B, . . . , **422**N when the method **400** is subsequently performed.

The fabrication of individual thin film energy absorption sheets **102** using a roll-to-roll process and then fabricating a multiple energy absorption sheet energy harvesting device **100** using a roll-to-sheet process addresses the deficiencies with existing solar cells noted above. Solar cell efficiency is improved by providing an energy harvesting device having multiple junctions corresponding to the multiple energy absorption layers of the device. Existing multiple junction solar cells are difficult to manufacture. The techniques disclosed herein by comparison ease manufacture, by fabricating the energy absorption layers prior to manufacture of the energy harvesting device itself, within corresponding thin film energy absorption sheets. Such prefabricated thin film energy absorption sheets are then just mechanically stacked and bonded together to form a multiple energy absorption sheet (i.e., a multiple junction) energy harvesting device.

Furthermore, different types of energy harvesting devices can be easily fabricated by appropriately selecting among different rolls of prefabricated thin film sheets. For example, one application may specify energy absorption sheets tuned to absorb different electromagnetic wavelengths, whereas another application may specify energy absorption sheets tuned to absorb the same electromagnetic wavelength. If the energy harvesting devices are otherwise identical, fabricating the devices for the first application as opposed to the second application can be as straightforward as switching out particular rolls of prefabricated thin film sheets for other rolls.

The methods as described above are used in the fabrication of integrated circuit chips. The resulting integrated circuit chips can be distributed by the fabricator in raw wafer form (that is, as a single wafer that has multiple unpackaged chips), as a bare die, or in a packaged form. In the latter case the chip is mounted in a single chip package (such as a plastic carrier, with leads that are affixed to a motherboard or other higher level carrier) or in a multichip package (such as a ceramic carrier that has either or both surface interconnections or buried interconnections). In any case the chip is then integrated with other chips, discrete circuit elements, and/or other signal processing devices as part of either (a) an intermediate product, such as a motherboard, or (b) an end product. The end product can be any product that includes integrated circuit chips, ranging from toys and other low-end applications to advanced computer products having a display, a keyboard or other input device, and a central processor.

The descriptions of the various embodiments of the present invention have been presented for purposes of illustration, but are not intended to be exhaustive or limited to the embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the described embodiments. The terminology used herein was chosen to best explain the principles of the embodiments, the practical application or technical improvement over technologies found in the marketplace, or to enable others of ordinary skill in the art to understand the embodiments disclosed herein.

We claim:

1. An energy harvesting device comprising:

a plurality of energy absorption cells;

a backplane sheet that is common to and that is contiguous across the energy absorption cells along a first axis, each energy absorption cell extending along a second axis perpendicular to the first axis;

a plurality of prefabricated thin film energy absorption sheets attached to the backplane sheet, each energy absorption sheet segmented in accordance with the energy absorption cells along the first axis, each energy absorption cell encompassing a segment of each energy absorption sheet, the thin film energy absorption sheets organized in a stack, including a top sheet, a last-from-bottom sheet, and a bottom sheet, each energy absorption sheet attached to at least one other of the energy absorption sheets and comprising:

an energy absorption layer segmented along the first axis in accordance with the energy absorption cells and made of a semiconductive material absorbing electromagnetic energy, segmentation of the energy absorption layer along the first axis defining gaps between adjacent energy absorption cells;

a top electrode contact layer and a bottom electrode contact layer, both the top and bottom electrode contact layers segmented along the first axis in accordance with the energy absorption cells and in contact with the energy absorption layer; and

a backside layer that is common to and that is contiguous across the energy absorption cells along the first axis; and

a plurality of pairs of vias, each pair of vias corresponding to a corresponding one of the energy absorption sheets, each pair of vias filled with a conductive material, a first via of each pair of vias extending from the backplane sheet through the stack to the bottom electrode contact layer of the corresponding one of the energy absorption sheets, a second via of each pair of vias extending from the backplane sheet through the stack to the top electrode contact layer of the corresponding one of the energy absorption sheets; wherein

within each energy absorption sheet, the top electrode contact layer is physically separated from the bottom electrode contact layer by the gaps between adjacent energy absorption cells,

the backside layer of the last-from-bottom sheet is attached to the top electrode contact layer of the bottom sheet, and

the backside layer of the bottom sheet is continuously attached to the backplane sheet.

2. The energy harvesting device of claim **1**, wherein:

the energy absorption layer of the bottom sheet of the plurality of energy absorption sheets absorbs electromagnetic energy of red visible light wavelength;

the energy absorption layer of the last-from-bottom sheet of the plurality of energy absorption sheets absorbs electromagnetic energy of green visible light wavelength; and

the energy absorption layer of the top sheet of the plurality of energy absorption sheets absorbs electromagnetic energy of blue visible light wavelength.

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